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THE RELATIVE EFFICIENCY OF SINGLE VERSUS MULTIPLE EXPOSURES IN THE RAPID MEMORIZATION OF VISUAL FORMS[1]

L. C. STECKLE

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INTRODUCTION

The role of time in the impression-learning-reproduction process is one of rather great theoretical importance and practical interest. This problem has lacked neither experimental investigation nor theoretical explanation, albeit today it is still somewhat shrouded in mystery.

The factor of time is fundamental to the Lepley hypothesis (25) and to the underpinning of Hull's description of learning in terms of the conditioned response (15). In fact, Loucks (26) has insisted that the Lepley hypothesis stands or falls with the demonstration that the formation of remote excitatory tendencies is or is not primarily a matter of the *rate of presentation* at which learning takes place. Evidence to the effect that some such temporal relationship does obtain has been presented recently by Hovland (14) who in accordance with the rather explicit demand of the theory and recent tradition in the area, used the anticipation method of presentation.

It might be argued that the anticipation method, in and of itself alone, establishes just those conditions under which the doctrine of learning as delayed conditioning operates. It perhaps would be instructive to attempt to discover whether or not the

[1] Part of thesis presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy at The Ohio State University. The writer wishes to thank Professor Samuel Renshaw not only for careful guidance in the selection of the problem, but more particularly for instruction in the interpretation of the results.

same mechanism subserves the learning process under a condition of presentation not expressly designed for that purpose.

MATERIALS AND METHOD

The method used in this study was one demanding an immediate reproduction on the part of the subject of a series of digits exposed for a given period or periods of time. That is, a test card containing a list of digits would be presented to a subject for a definite interval or series of intervals. Immediately at the cessation of the exposure period or periods, he would be requested to reproduce that number. A detailed account of this procedure will be presented later.

Preliminary Procedure and Subjects

When any attempt is made to describe the effect of the variation of a given situation upon any process of animal behavior it is obvious that any other variable which might have a part in the result should be controlled as adequately as possible. In a problem such as this where a particular performance is to be tested by varying techniques over a relatively long period of time, it is imperative that one be as certain as possible that the subjects should remain on the same relative plane as that on which they started. Absolutely, such a criterion is manifestly impossible; relatively, it is quite within our control. Concerning this point Koffka (22, p. 503) says: "The process occurring at the moment of reproduction depends, therefore, on a very complex set of conditions, which it is impossible to unravel in each particular case. Experimentation will have the task of establishing as simple conditions as possible so that 'pure' cases may appear; i.e., cases in which one of the many conditions has a dominating influence. Such pure cases would reveal the actual factors at work."

In the particular situation which presents itself here, in which an attempt was made to determine the relative virtues of, say, single and multiple exposures in the memorization of digits, it is of the utmost importance that such masking effects, as example practice, be eliminated as completely as possible. It plainly

would be absurd to attempt to measure the rôle played by changes in any given variable while the subjects were continually becoming more proficient in the task. An illustration of this statement will be presented later.

It was therefore necessary that the subjects used here should be highly skilled in the memorization of a digit series of that length to be used in the experiment proper. Training was given toward that end.

The three subjects who were to be practiced had all served in a like capacity for either Schwarzbek (39) or Knight (21) and hence came into the situation with a thorough knowledge of the problem and with their own methods of memorization well established.

These subjects were given training following the technique developed by Schwarzbek (39). That is, they were brought into the experimental room and instructed to reproduce the exposed number immediately at the cessation of the exposure. They were to do this as accurately as possible and to feel free to revise or correct at any time. The number could be reproduced in any desired order and guessing was permitted. When a number was correctly reproduced (each digit correct and in its proper place) the exposure time was cut by one tenth and another number shown. This procedure was repeated until several sittings showed no improvement. These final times were close to world record performance. A résumé of the improvement is shown in Table I.

Since the most rapid reported time for memorizing a series of digits of the length used here is 0.811 sec. by Wright (Banner (1)) and 0.824 sec. by Finklestein (Schwarzbek (39)), it is apparent that these subjects were highly skilled in this particular act, when it is remembered that Wright and Finklestein approached virtuosity in rapid memorization.

Two relatively untrained subjects were also used. These individuals had never served in any similar experiment and were quite untrained in rapid memorization. Some practice was given them, of course, to permit of familiarity with the experimental procedure. Then also, as Table II will show, it was a matter of

convenience to permit them to a lower their memorizing time since the amount of time necessary for a novice would make for an extremely cumbersome situation.

All subjects were male graduate students, O, S, M, and W in Psychology and H in Mathematics. They were interested in the experiment itself and particularly in their own performance, since rather keen competition existed among them in the establishment of these final times (Tables I and II). Hence they were willing and hard workers, and the problem of motivation settled itself.

TABLE I

Initial and Final Times for Skilled Subjects

SUBJECTS	INITIAL TIME	FINAL TIME	NUMBER OF SITTINGS
	seconds	*seconds*	
O	30.0	0.977	22
S	20.116	1.236	15
M	10.018	1.230	18

TABLE II

Initial and Final Times for Unskilled Subjects

SUBJECTS	INITIAL TIME	FINAL TIME	NUMBER OF SITTINGS
	seconds	*seconds*	
W	45.032	3.550	6
H	45.089	2.232	10

Materials.—The material used consisted of 12 place typewritten digits placed on matte white 5 x 8 cards the reflection factor of which was .82 (Figure 1). In this preliminary experiment anywhere from ten to twenty such cards were exposed during any one sitting. Each number was exposed once only. The amount given was determined by the subject. Fifteen was about optimum but more were given when the subject felt that a successful reproduction was about to be made. Fewer were given when for any reason the subject was fatigued or felt incompetent.

Experimental Procedure.—In a problem such as this where the task is rather consistently presented to the subject in varying

form, it is important that in each instance the observer should be permitted sufficient opportunity in adjusting himself so that he may handle the problem as effectively as possible. To attain this end the subjects were presented with each series several times over a period of about two days. Each "series" consisted of ten cards each bearing a single twelve place number. Any given sitting was composed of the presentation of these cards with a subsequent reproduction of each.

Five sittings were given under each varying condition of exposure. The availability of the subjects established the intervals at which these sittings were made. It was found convenient to have them at the following time:

First Sitting	8–10 a.m.
Second Sitting	4 hours later
Third Sitting	8 hours later
Fourth Sitting	24 hours later
Fifth Sitting	32 hours later

4 9 8 5 0 3 2 7 9 6 8 1

FIGURE 1

In this manner each subject had five practice sessions with series (except in a few instances when for one reason or another, the observer could not work). Measurements could thus be made under each condition of presentation over a period of time during which the subject had ample opportunity to make whatever adjustments were necessary.

Before beginning the sitting under any given conditions of exposure, the subject was told how the exposures would be made. A sample card was also shown him under the exposure conditions to be used in this particular series of sittings. This card was presented in precisely the same manner as the test cards which were to be shown later. In this fashion the observer knew what to expect and was consequently better able to handle the experimental situation when it arose.

The chronological order of the sittings with their varying conditions of exposure are shown in Table III.

The function of the near-threshold exposure time (one second) was for the purpose of establishing a sort of base from which to advance. In the case of the "untrained" subjects this "threshold" exposure time was two seconds in duration.

Since it had already been established (Table I) that the skilled subjects were able to memorize a twelve place number in the neighborhood of one second, the total exposure time to be given under varying conditions was set at three seconds. This interval was chosen because it was amenable to division and because it

TABLE III

Exposure Condition for Each Sitting

Condition of exposure should be interpreted as: 1 SE, single one second exposure; ½–½, one-half second exposure, one-half second blank interval, one-half second exposure, total exposure time being one second; 3–SE, single three second exposure; 1–3–1, one second exposure, three second blank interval, one second exposure, for a total exposure time of three seconds; etc.

SITTING	CONDITION OF EXPOSURE
1	1–SE
2	1–3–1
3	3–SE
4	1–2–1
5	1–1–1
6	1–½–1
7	3–SE
8	1–3–1
9	½–1–½
10	½–½–½
11	½–½
12	1–SE
13	1–2–1

was well above the threshold. It seemed reasonable to assume that if the total exposure time were demonstrably long enough to permit near perfection in reproduction, and the subjects were trained to a degree approaching virtuosity, that whatever might happen to the performance under varying conditions could well be attributed to the situational variation. That is, if an individual is highly skilled under stated conditions in any given performance, then he should be equally as efficient under another set of conditions provided, of course, that this latter situation is

equivalent to the former. Also, whatever change may take place in the performance may reasonably be assumed principally to be caused by the condition change. Particularly would this be true should the performance alteration endure over a period of time or as long as the change of condition might be operative. Additional support would be lent to the assumption if the performance should immediately return to its former level with the onset of the original conditions. Specifically then, given highly skilled subjects, if frequency is the paradigm of duration, the performance should be equally as effective under either situation.

In consequence of this argument, it was decided to measure performance under the varying conditions outlined in Table III. The subject would be given, say, a series of sittings in which each card would be given a single three-second exposure. In subsequent sittings this total three-second interval would be broken up into six one-half-second or three one-second exposures. The interval between the multiple exposures would also be varied by one-half, one, two, or three seconds. This inter-exposure interval was also varied so that measurements might be made on the performance as frequency more and more receded from duration.

APPARATUS

The special-design tachistoscope of which Schwarzbek (39) has given a completely detailed description, and which has also been described by Banner (1) and Knight (21), was used in this experiment. Since the studies of the above individuals have already given detailed accounts of this apparatus, it may be but briefly described here.

The subject was seated under a black cloth canopy which effectually screened him from extraneous light. He looked through an aperture into the tachistoscope body at a pin-point fixation light in the plane at which the material was to be exposed. A Cenco Illuminator, No. F 6825 provided the exposure light source. Illumination from it passed through a series of lenses appropriately arranged to light that part of the material card to be exposed to the subject. A magnetic shutter was located at the point where the ray sheaf converged. A thin alu-

minum template was placed in the optical system at a point comparable to that of the slide in a slide projector so that the boundaries of the light area delimited by it were sharp and clear. This area was one and one-half inches wide and extended the length of the test card. The material to be exposed was placed in the approximate center of this lighted area. The brightness at the test card was kept at about 10 apparent foot candles throughout the course of the experiment.

An electrical hook-up accessory to the magnetic shutter of the tachistoscope was devised so that exposure intervals rigidly could be controlled.[2]

RESULTS

Effect of Exposure Conditions upon Amount Reproduced. The relation between the number of digits correctly reproduced (each digit correct and in its proper sequential position) and the condition of exposure are shown in Figure 2.[3]

This figure is presented principally to demonstrate the rather remarkable similarity of performance of each subject under each exposure condition. All subjects tend to maintain their respective positions from series to series.

A rather interesting curve is derived when the amount reproduced after a three-second exposure and under conditions when the exposure interval is no shorter than one second is considered. This appears in Figure 3. (Justification for this "average" curve may be found in the individual curves shown in Figure 4.)

In Figure 3, the performance level attained with a three second single exposure was established as a base and the levels reached under other exposure conditions compared with it. It may be seen that a rather definite relationship could be asserted to exist between the variables plotted.

The general shape of this curve is strikingly similar to those obtained by Köhler (23) and Pratt (33) in their investigations of

[2] Details of this device are given in the writer's thesis on file at the Ohio State University Library.

[3] The rather lengthy tables embodied in the thesis proper are omitted here.

the time error in psychophysical judgment. It might well be held that these data demonstrate a weakening or sinking of the memorial "trace" as time goes on.

If the same general processes are involved in both simultaneous and successive exposures, some very interesting parallels might here be drawn. Before attempting any such generalizations, however, it seemed wise to check those points which made such a comparison possible, i.e.:

A. One second exposures with a two second interval, and

B. One second exposures with a three second interval.

Figure 5 shows the outcome of these checking experiments. Here the percent reproduced under the two above mentioned conditions are those obtained when these exposure conditions were repeated after the subjects had had about four weeks *practice* in memorizing under the conditions of successive exposure. It may be seen that the apparent relationships no longer hold. Now, all methods are approximately equivalent as regards reproduction.[4] One rather important fact appears from a comparison of Figures 3 and 5. This has to do with the effect of *practice* upon the performance under the conditions of successive exposure. Unquestionably the subjects had improved. Figure 6 shows the results on the untrained subjects under the same exposure conditions.

Since the subjects were highly skilled under the condition of simultaneous exposure before any of these measures were taken, such results should not have been obtained providing the conditions of memorization are the same under both simultaneous and successive exposure. Perhaps, however, only a general practice effect had been measured and the observers were not as highly skilled as had been supposed. To check this point, another series under the condition of a single, 3 second exposure was made. The results appear in Table IV.

It will be remembered that the second series in Table IV was given after about four weeks practice under conditions of *suc-*

[4] Cf. Needham, J. G., "The time-error as a function of continued experimentation," *Amer. J. Psychol.*, **46**, 558–567.

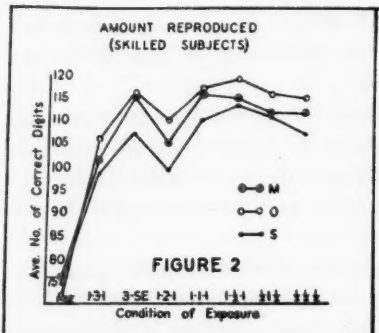

FIGURE 2

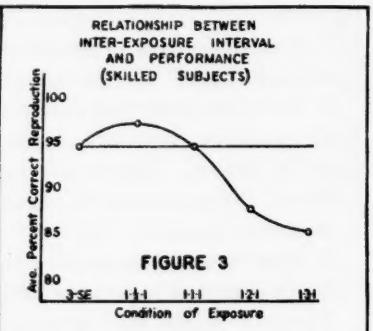

FIGURE 3

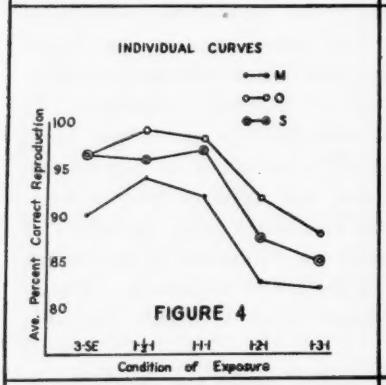

FIGURE 4

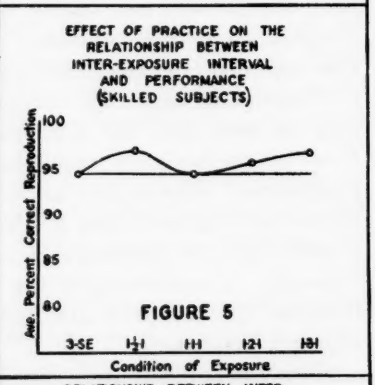

FIGURE 5

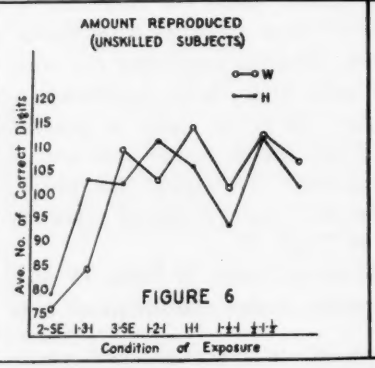

FIGURE 6

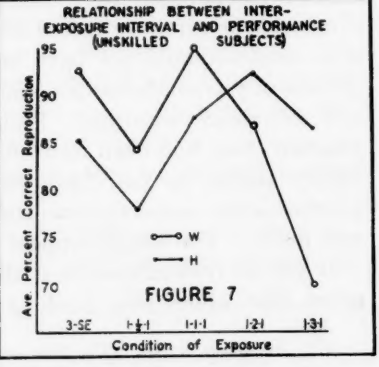

FIGURE 7

FIGS. 2–7

cessive exposure. Apparently the results shown in Figure 3 were not due to a general practice effect, but only to one rather specific to the condition of successive exposure.

Such observations would tend to indicate that a rather striking difference exists between the memorization task under the varying conditions of simultaneous and successive exposure. If the processes subserving learning approach identity under these two varying conditions there seems to be no reason why such results should be obtained. If it were true that " . . . a biological adaptation is more pronounced if, instead of being adaptation to a short experience, it is to one prolonged or frequently repeated," (30, pp. 182–3) and thus simultaneous and successive exposures were equivalent, practice should not be specific to each separately.

TABLE IV

Stability of Performance under the Single Three Second Exposure (Skilled Subjects)

SUBJECTS	AMOUNT REPRODUCED*		RATIO
	1st Series	2nd Series	
O	107	108	1.01
M	116	118	1.02
S	116	116	1.00

* Number of digits *correctly* reproduced out of the possible score of 120.

If anything, we should expect facilitation as Robinson (38), Harden (12), Johnson (20), Wylie (44), Hunter (17) and others have shown.

It would seem that in the above reported account there lies a general criticism of a large amount of psychological investigation. Too often in reported work is the factor of practice inadequately considered or entirely ignored. As Schwarzbek (39) and Banner (1) have indicated, the limits to which a docile organism can be trained are unknown, and those to which he may attain can test credulity. In the face of results such as these, it is probably not good procedure to bring subjects into a learning situation, the conditions of which are to be varied, without first being as certain as possible that when the situation is changed, what occurs to

the process being studied is, primarily at least, the result only of the variation.

In that Boring (3) has pointed out that under the condition of highly skilled subjects, we may accept fewer cases than ordinarily we would use, since the observer's judgment under these conditions is less subject to variation, large numbers of cases may not be entirely necessary.[5]

This criticism is, of course, not original. Johnson (19), Carr (6), and Melton (28) have argued for standardization of general methodology in psychological experimentation, and hold such to be propaedeutic to the systematization of experimental facts. Further support for this argument appears in Figure 6 in which

TABLE V

Effect of Practice on Threshold Performance

T	AMOUNT REPRODUCED*		RATIO
	Original Series	Repeated Series	
Trained Subjects			
O	74	82	1.11
M	72	77	1.07
S	76	75	0.99
Untrained Subjects			
H	79	98	1.24
W	76	105	1.38

* Number of digits *correctly* reproduced out of the possible score of 120.

data from the unskilled subjects appear. Here uniformity of performance appears only in the latter portion of the curves after the observers had served for a period of about five weeks.

Table V argues for the point still more. Here the results are given from the measurements made at the threshold exposure time for both groups of observers. The data presented represent results obtained with the original series and a repetition of this condition of exposure made ten weeks later.

Here it may be seen that while the skilled observers (O, M and

[5] In this connection, cf. Goldstein, K., "The Organism," American Book Co., New York, p. 26f.

S) remain relatively constant in their performance, the unskilled observers (H and W) show rather large practice effects.

Practice effects, however, are not the sole criterion of differentiation between the conditions of simultaneous and successive exposure. The *bases* for the occurrence of such habituation phenomena constitute a perhaps yet more powerful argument for a distinction between the two. These bases, it seems, lie in the manner in which the problem is attacked by the subject and in his response to the conditions imposed by the task.

It has already been shown (39), (21) that the behavior of a trained observer, as in other acts of skill, is smooth, executant and ballistic. This is in contrast to the rather jerky, spastic tactics of the novice. Such differentiation is unquestionably real, as anyone may discover. The basis for this distinction seems to lie in the changes in technique which take place concurrent with improvement.

In a problem situation of this kind the novice exhibits a markedly individual type of behavior. When a number-to-be-learned is presented to him his response is somewhat as follows:

A particular bit (group) of the number is phenomenally isolated and this bit observed and repeated (either vocally or subvocally) over and over again. When this first "group" is believed learned, another is attacked in the same manner and so on until all digits have been accounted for. Each individual digit is functionally a unit and is embodied with others into a group by the sheer force of repetition. This technique is akin to that involved in learning material which is serially presented.

This process is cumbersome and, by virtue of its artificiality, extremely subject to error. The proper budgeting of the total exposure time is also not the least of the problems facing the beginner. The task of isolation and *maintenance* of a desired group presents a problem almost incapable of solution at this stage. Extraneous numbers continually creep in or digits within the group are omitted. The group has here no stability and commonly all error goes unrecognized.

In contrast to this, the skilled observer "scans" the presented number. The total process involved in the acquisition is a

smooth, flowing one. Groups have become units within which the individual digits do not roam but remain held to their original relationships. Errors of omission are rare and when an error of any sort does occur, it is usually recognized. That is, *after* a reproduction has been made in which an error has occurred, the subject commonly reports that there was something wrong with a given group and may even state the position of the error although being incapable of correcting it.

As practice continues and the individual becomes more and more able, the process becomes smoother and more fluid; reproduction takes place with greater and greater assurance and groups attain a larger functional unity.

Now when the skilled observers were presented with the condition of successive exposure their first attack, was, of course, to handle the problem in the manner in which they were accustomed. That is, during a first exposure they "scanned" the number with the greatest emphasis being placed on the first group. During a second exposure the second groups would be emphasized, etc. Difficulty, however, immediately began to appear. Partly because no single exposure was sufficiently long adequately to *complete* the number and partly because the total behavior was being *interrupted* by extraneous factors, their performance was not greatly better than that which obtained with the threshold exposure. The scheme which operated so efficiently under the condition of simultaneous exposure, here completely broke down. Search, then, for a method which would function was at once begun.

The technique finally hit upon was nothing other than a return to the practices of the beginner. The behavior now occurred something like this:

During the first exposure a subject would observe the first group (usually 4 digits) of the 12 place number. This group would be repeated as many times as possible while *looking* at the remaining eight digits. During the second exposure, the first two groups would be checked and repeated while looking again at the last group. In the third exposure the entire number was scanned.

It was apparent here that a number as a whole has lost its unity

and has become primarily two groups of four digits each, with an appendage of four digits which in reproduction is sort of dragged forth by the preceding eight. The performance as a whole has lost its smoothness and has become broken up into two and perhaps three rather separate, individual bits of behavior.

The necessity for such transformation of method was a source of annoyance to the subjects and entailed the expenditure of a greater amount of energy. Under these conditions the task of correct reproduction became much more difficult. It follows then that although reproduction may be as efficient under the conditions of successive exposure as under the condition of simultaneous exposure, *the subject is forced to work harder to make it so.* This alone would argue for a discrepancy between the two conditions.

The unskilled subjects, on the other hand, preferred the condition of multiple exposure. The reason is obvious. Such exposure conditions work into the method used by the beginners, i.e., that of deliberately breaking up the number and treating it as a succession of small bits. The successive exposures were of definite aid in the isolation and maintenance of groups and were actually used for that purpose. Their procedure differed, however, even here from that of a skilled observer, in that each exposure (or in the case of the six one-half-second exposures, each two exposures) served to delimit a separate group. That is, in one exposure the first group alone would be taken. In another exposure the first two groups would be taken; the first one repeated only, the second one emphasized. In the last exposure, the entire number would be run over with the last group being stressed.

There are, then, at least two bases upon which a distinction between the methods of simultaneous and successive exposures may be said to rest, i.e.:

1. Their relative independence as regards practice effects.
2. The varying modes of attack to which each gives rise in subjects.

DISCUSSION

In the light of recent learning theory and with special reference to pedagogical and remedial techniques, the question of the rela-

tion of successive to simultaneous stimulation is of importance. Recently M. Meyer (30) in justifying and elaborating upon a much earlier (29) concept made the following statement: "It is self evident that a biological adaptation is more pronounced if, instead of being adaptation to a short experience, it is to one prolonged or frequently repeated." Here is a clear identification of the two methods of stimulation.

Hull's theory (15) demands for general applicability, that the process or processes subserving the two objectively different modes of impression be the same. His derivation of a complete theory of learning from the Lepley hypothesis (25) is determinable by the demonstration that the formation of remote excitatory tendencies is primarily a matter of the *rate of presentation* at which learning took place (Loucks, 26). That is, it becomes necessary to show that learning itself, in the same fundamental manner as delayed conditioning, becomes established to a span of time. If this is true, then the learning process as delayed conditioning should exhibit a marked relationship to the temporal interval or intervals used in its formation. The importance of the temporal aspect of stimulation sequence in the conventional conditioning experiment has been shown by the work of Switzer (40), Wolfle (42) and others. That some similar sort of relation exists in the more usual learning situation has yet to be demonstrated.

The results of this experiment are pertinent here. The data portrayed in Figure 3 are of particular interest. In it may be found almost an analogue of the curve obtained by Wolfle (42) showing the relation between stimulation sequence and speed of conditioning. The optimum interval between the conditioned and the unconditioned stimuli she found to be 0.5 second. In Figure 3 an advantage in terms of percent correctly reproduced may be seen to accrue to that condition of exposure in which the inter-impression interval was also 0.5 seconds. This point, however, as Figure 4 will attest, is the only one at which all subjects did not agree; subject S showed practically no difference in performance at any of the first three conditions of exposure. Figure 5 is also pertinent. Here the effect is shown of specific

training under the condition of successive exposure. It will be noticed that now all conditions have become essentially equivalent where the amount reproduced is concerned.

From data such as these, three things are evident:

1. There is an optimum type of exposure sequence. (Figures 3 and 4 which resemble rather strikingly that found in conventional conditioning.)

2. That the data portrayed in Figures 3 and 4 are experimental artifacts which vanish (Figure 5) under more rigorous control.

3. That reproduction, as such, is a poor measure of what actually is taking place under these conditions.

Now, statements 1 and 2 cannot be both correct, while 3, if true, would cast serious doubt upon 1 and could be either confirmatory or antagonistic to 2 depending upon the outcome of whatever extra-reproduction functions could be analyzed. A discussion of statement 3 will be taken up later while the evidence for and against statements 1 and 2 will now be considered.

As was pointed out earlier, whenever the effect of the variation of conditions of occurrence upon any given process is to be determined, it is imperative that a most rigorous examination be made of the possible influence of other, perhaps unexpected, factors. In such a study as this, the above problem becomes a paramount issue. It is obvious that some sort of pre-experimental training is necessary. This training, of course, was given. Now since the subjects had been highly trained under the condition of simultaneous exposure, Figures 3 and 4 become incapable of interpretation on the basis of any postulate that assumes an identity between the conditions of successive and simultaneous impression. It would seem true that if the two conditions are identical, then training in one should, by definition, constitute training in the other. Such was not found to be the case.

However, if this identity holds only within certain temporal limits (as the results of Wolfle (42) would indicate) then on the basis of Figures 3 and 4 one could say that those limits fall within one second of time. With some such concept the proponents of learning as conditioning could be in whole-hearted agreement. But how shall the results of further training specifi-

cally in successive stimulation be explained (Figure 5)? Can it be that the situation represented in Figure 3 actually obtains since it is a measure of the basic process prior to its alteration by practice? This, of course, assumes that by practice a previously "optimal" interval loses its potency in respect to the other temporal sequences used. In terms of the conditioned reflex this would mean that training can somehow increase the temporal duration of the excitatory tendencies which presumably subserve the learning mechanism. That is, through practice beyond the stage of arousal, delayed conditioned responses become stronger, more endurable and more easily elicited. Some slight evidence for such an assumption might be gathered from Switzer (41), who showed that the anticipatory character of the galvanic skin response tends to move forward and become stronger as time elapses following complete experimental extinction. This means that the effect of the inhibition of delay presumably operative during the trace or delay period becomes progressively weaker as time goes on although highly functional immediately after training and prior to extinction. If this is true, then under our conditions training might very well transform an originally "poor" condition of exposure into one the results from which become quite comparable to those obtained under a stimulation sequence originally "good."

Now, by "originally" good or poor we may mean that what actually takes place under an "originally good" condition of exposure is that which occurs when the ordinary, untrained individual is so stimulated, for instance, in the classroom or clinic. If learning under such conditions follows in general the temporal demands of the conditioned response, then such phenomena should certainly exhibit themselves when untrained observers are used. Figure 7, in which is plotted the data (cf. Figures 3 and 4) from *untrained observers, fails to bear out this assumption.*

Perhaps the qualitative data from the experiment may also be to the point here. It will be remembered that under the condition of simultaneous exposure a very definite *skill* in memorizing was developed. (This point has been elaborated by Schwarzbek

(39) and Knight (21).) It was also pointed out that under the conditions of successive exposure, this skill was broken down and the subjects regressed to an older, less efficient type of behavior. It might also be emphasized that never throughout the course of the experiment did the subject's performance under the condition of successive exposure attain the confidence so characteristic of the process when a single durational exposure was given. Under the former situation the trained subject had to expend considerably more energy to attain the same level of performance which typified his behavior during simultaneous exposure.

It would seem then that even when more than due allowance is made for the functioning of the temporal aspect of the mechanism of the delayed conditioned response in the rapid memorization of digits, scant evidence in its favor is obtainable.

A point of emphasis throughout has been on the role played by the learner himself in the learning situation. It has been shown, at least in the customary terms of reproduction, that when the *masking effect of practice has been removed, subjects do approximately equally well under quite varied conditions of stimulation.* This can only mean that attempts to explain the learning process in terms of the stimulus situation can at best but approach half-truths. The point of view that the individual himself determines to a large extent the direction of the perceptive or memorial process, certainly is not new. Hempsted (13) reported that the reproduction of visually presented figures was individual-influenced, habits and experience playing a dominant role. Judd and Cowling (18) in studying the changes occurring in the reproduction of seen figures said: "Whenever a change occurs in conscious experience as a result of practice, the elements of the experience are sure to undergo a rearrangement of such a character that they will be more easily discovered than a relatively static experience which is undergoing no marked development."

Freeman (10), investigating the same problem, held that the organism must be actively engaged during the perceptual process and not be passively receptive if skill is to be obtained. Knight (21) reports that the process possessed the characteristics of

anything but those of a photographic plate. Freeman (10) also pointed out that the perception of form passes through at least three stages:

1. "Level of predisposition" which refers to the same phenomena termed later by Gibson (11), Carmichael (5) and Knight (21) as, roughly, the effect of instruction either self-imposed or offered by the experimenter.

2. "Generation of thingness." This, of course, has been called by Bartlett (2), the "effort after meaning."

3. "Recognition of object," i.e., the formation of a specific configuration; called by Bartlett (2) "naming."

The specific effect of instruction upon the observer was investigated by Carmichael, Hogan and Walter (5), and by Knight (21). Both studies agreed that the reproduction of a figure is more a function of language than of the nature of the figure structure itself. This figure-observer relationship has received rather great emphasis by Purdy (34), (35), (36), (37) in his development of a motor theory of perception.

It must, therefore, be conceded that *instructions* (or, perhaps, how the observer views the task at hand) are tremendously important in determining the way in which he will deal with and ultimately solve the problem. Now "instructions" are fundamentally a rapid and easy means of "practicing" or training a subject, when the task is such that through the language of speech or pantomime we can do so. In other problems, such as the present, it becomes necessary that the observer be actually practiced in the task itself, since it is a manifest impossibility for one individual to tell another how he is able to reproduce a twelve place number in, say, 1.5 seconds. The "instructions" here must be almost entirely self-imposed and involve an adoption of a method which results in an "aesthetic appreciation" of the task (Knight, 21). Anyone who is proficient in a skill will recognize what is intended here; the "glow" that accompanies a perfect movement, perfectly executed.

The purpose of such "instruction"—whether it be given or learned—would appear to be a leveling one; a technique for starting all subjects at the same point. It is a method of control.

This concept has, however, too often been bowed to, and passed; making certain that the results obtained would be unreliable. Particular reference is made here to the technique of bringing several hundred college students into a laboratory or classroom, presenting them with the same general problem under a variety of conditions, and attempting through the results to specify those conditions under which learning may be optimal. The recent reports of Leeper and Leeper (24) and of Wolfle (43) are cases in point.

Whenever an attempt is made to measure the influence of variation upon any process, one should be certain that all subjects are functioning on the same general plane of performance and that this plane is sufficiently stable to endure throughout the experiment. It would seem better to use fewer but more competent subjects whose observations are consistent one with the other so that any measurements made upon them becomes a fairly exact indicator of the average conditions which prevail throughout the experiment.

An examination of Figure 2 will indicate the rather striking conformity of the trained subjects used in this experiment throughout the total series of measurements. These may be compared with Figure 6 where comparable data are plotted from the untrained subjects. Here our data certainly agree with Boring when he said: "The importance of practice lies . . . in its effect upon constancy of judgment" (3).

Attention has been called to the "regressive" behavior of the trained subjects under the conditions of successive stimulation. It was pointed out that under these conditions the subjects were forced, if reproduction was to be efficient, into an older, more time-consuming method of memorizing. Processes of verbalization and articulation were brought into play entailing a considerably greater expenditure of energy. As was indicated, even where through training, reproduction became as efficient as it was under simultaneous stimulation, the task quite definitely was *more difficult.*

Under these conditions then, one might say that if the mechanism underlying the performance of the subject partakes of the

formation of the delayed conditioned response, then the period of delay requires additional supports or carriers for its completion and maintenance. That is, for an excitatory tendency to bridge a temporal gap necessitates the functioning of some extraneous reinforcing and stabilizing activity. No evidence was found here which might tend to indicate that the delayed conditioned response, if formed at all, was capable of functioning throughout a temporal gap by and of itself alone.

Some evidence pertaining to the rapid memorization of digits has been accumulated which may be, in part at least, explanatory. Both Schwarzbek (39) and Knight (21) emphasized the fleetingness of the impression; "traces" left by the process were reported as weak and unstable. Osborn (32) in reporting the phenomena of "winging a part" (the learning of an entire role by memorizing the parts in the wings between scenes) found that one result was that the words did not remain; they seemed to fade as rapidly as they were acquired. The ability to perform this act involved much practice and long experience.

Similar observations were continually made throughout this experiment. It seemed *as though* the subject had a very definite job to do and only a very limited time in which to do it. The reproduction exhibited a definitely "must" characteristic. The problem involves an extreme nicety of judgment and technique. If the problem is to be solved at all, it must be at once; subsequent to the cessation of impression. Whatever factors or processes are involved are in a state of extremely labile equilibrium. From this, it would seem apparent that whenever any delay of whatever sort is forced upon the subject, he must fall back upon some accessory supporting techniques in order to maintain a relative state of efficiency. Schwarzbek (39) reported that often a period of delay inserted between the cessation of impression and the beginning of the reproduction served to make for better reproduction. Such cases were here extremely rare.

Further evidence against the formation of excitatory tendencies as delayed conditioned responses may be found in the location of error in the reproduction. Table VI gives the percent of all error that occurred in respective thirds of all numbers. The

data from both trained and untrained observers are shown here. If Hull's diagram (15, p. 502) is illustrative of the manner in which learning takes place then the majority of error should have occurred in the second or center third of the numbers rather than in the last third. In regard to the occurrence of error, the final third of all numbers is definitely the "worst." Both types of observers agree to a remarkable extent where the positional characteristic of error is concerned. Here at least, is one instance in which practice as such has but little influence. Since this is true, it may reasonably be stated that as regards error-location the proposal for a learning theory as indicated by Hull (15) does not apply. Banner (1) in her analysis found that error tended to increase from left to right for all lengths of numbers.

TABLE VI

Successive Thirds of All Numbers

	FIRST THIRD PERCENTAGE OF TOTAL ERROR	SECOND THIRD PERCENTAGE OF TOTAL ERROR	THIRD THIRD PERCENTAGE OF TOTAL ERROR
Trained S's	11	30	59
Untrained S's	16	30	54

Perhaps it might be held that since each group was functionally a unit, what actually occurred was that the conditions outlined in Hull's schematic diagram apply only to the individual groups rather than to the entire number itself. It can only be answered that there was no evidence for the errors *within* the group to be limited to the central digits. It was just as likely for the end digits to be erroneously reproduced.

Still further evidence presents itself. If learning involves the formation of excitatory tendencies as advocated by Hull (15), then errors of anticipation or inversion certainly should be predominant. The "place skipping tendencies" of Mitchell (31) and the "errors of anticipation" of Lumley (27) have actually been used as evidence for this concept (16). On the basis of this theory it might well be expected that a similar sort of error should principally be represented here. Schwarzbek (39) found the errors of inversion to be of somewhat greater occurrence when

wholesale omissions (such as took place when an observer "quit" in reproduction) were disregarded. Banner (1) scoring all error found the percent of occurrence to be: errors of substitution 49%; errors of omission, 33%; and errors of inversion, 19%. Both of these investigators used the simultaneous exposure only. An analysis of the errors made under all types of exposure in this study yielded the following: errors of substitution, 51%; errors of omission, 6%; and errors of inversion, 42%.

In connection with attempts at error analysis, it is of interest to note the absence of error attributable to any interference between numbers reproduced from two successive exposures. Even when the stage was set for such interference, it failed to occur. As example, one number in a series contained the digits "9847" as the central four. The immediately following number had for its central four digits "8974." Although both of these groups of four digits composed a subjective group, there was no evidence that the learning of the former interfered with the learning of the latter. In fact, subjects seldom, if ever, reported that they noticed any such similarities. Since the twelve place numbers could be made up only of the ten digits with two repeated (when greatest heterogenity was desired) such quasiduplications occurred fairly often. Schwarzbek (39) of course, has reported the same observation.

Such errors were also rare in occurrence from group to group within any total number. (Banner (1), Schwarzbek (39).) Their occurrence *within* a group (if inversions may be so classed) was considerably more common, by far the majority of all errors of inversion being within a group and being inversions of the first order, i.e., two consecutive numbers being interchanged.

One reason, perhaps, for the failure of any interference effect to evidence itself from one number to the next, may be found in the fact of the fleetingness of the impression mentioned above. That is, normally the impression seemed to vanish with the reproduction—a sort of "wiping the slate clean" activity. If this is real, as well as apparent and phenomenal, the absence of interference might be readily explained. The after effects of one exposure then simply do not endure up to or through the impression period of the following presentation.

It seems reasonable to assume that for interference to exhibit itself, there should be some actual interaction between the after-effects of impression. Such a concept would align itself with several modern interpretations. Whether one accepts the growing spiral of Dodge (7), the frame of reference scheme of Bartlett (2), or the trace aggregation concept of Koffka (22), the underlying principles are the same. A reasonable assumption would be that an "after-effect assimilation" takes time. That is, a residuum impression-aftermath would have to endure long enough to be incorporated into whatever frame of reference is operative at the moment. When such is not the case, no interference would be found; when such is the case, interference should exhibit itself. Such a concept readily should lend itself to experimental investigation.

It has already been suggested that reproduction itself may not be a valid measure of the processes underlying the subject's performance. W. Brown (4) makes a point here. His general conclusion is to the effect that a single recall makes for a fallible measure of the memorizing process. Melton (28) also holds that a single measurement is not a good indicator "of the average conditions prevailing throughout a series of measurements since it is partly, if not wholly, determined by variable factors."

In this experiment such factors as attitude, expenditure of energy, problem difficulties, "grouping," etc., are certainly to be considered as factors operative in the total memorizing process. Such factors are not indicated by any criterion of performance such as correctness of reproduction, nor can an experimenter, except that he be skilled in the practice, tell by the manner of the reproduction precisely how the subject grouped the material in learning it.

The point has already been considered that under the conditions of successive exposure the trained subjects were forced to work harder than under the condition of simultaneous exposure. It has also been stated that these subjects experienced more problem difficulty under the former condition of exposure. They also reported that they "didn't like" this method. None of these subjective responses become apparent when the sole criterion of performance is the correctness of reproduction. They can only

be observed through accessory reports brought out by questioning the subject specifically on them and instructing him to look for their operation. For an observer adequately to do this, he must be trained. Such a procedure is, of course, not always followed.

Schwarzbek (39) and Knight (21) repeatedly have placed emphasis upon the nature of the performance of memorizing in the skilled subject. The process of virtuosity in remembering, they report, is characterized by a smooth, ballistic performance, any deviation from which is lethal to its success. Knight (21) in particular reports that for mastery at any given sequence of preparedness-impression-reproduction, *all* of the activities that go to make up a successful performance must be operative, each to its required degree. Such requisites are characteristic of any skill. A masterful golf swing, driving the ball far and true insists that such factors as timing, ocular-skeletal muscular relationships, subjective feelings of ability-to-do, etc., be all coordinated to the finest degree. Otherwise, as Knight (21) has indicated, only failure, complete or partial, can result.

With such statements the present experiment is in complete agreement. It was observed, time and time again, that a successful reproduction always exhibited the smoothness reported by Schwarzbek (39) and the "esthetic gratification" reported by Knight (21).

Whenever this executant behavior was interrupted in whatever manner, the total process broke down. If, for any reason, a subject was "thrown off his stride" during impression by, for example, a zero in the digit series, some "unusual" number combination (20; 39), "stumbled" during reproduction, or interference was given by any saccadic movement such as sneezing, hiccoughing, etc., the failure of that particular attempt was guaranteed. The performance, in truth, had to be "a perfect movement, perfectly executed."

Knight (21) also reports that as performance becomes more proficient and stable, the role played by visual imagery becomes less and less. This also was found to be true, if by visual imagery is meant attempts to reproduce through "visualizing" the ex-

posed number. However, observations made during the course of this experiment tend to indicate that a type of visual imagery becomes of importance as the process develops. This particular "type" has to do with phenomena reported above, namely, the "must" characteristic of the reproduction and the necessity of arriving at the last part of the number to be reproduced before the recollection of it fades.

The function of imagery in the total process, under these conditions of experimentation, was something like this. The "scanning" process of the skilled observer during the exposure period involved an emphasis upon the first eight numbers (when the subject grouped in fours). Toward the end of the exposure interval a "snapshot" would be made *of* or *at* the last group. That is, one might say that the first two groups were learned while the last one was only very highly efficiently observed. In the normal left-to-right reproduction then, this last group seemed to approach something resembling a visual image. This was *not* an imaginal representation of the actual digits involved. It was rather a *feeling* that "out there" (in space, perhaps) was a sort of gradually fading patch of light which *must be reached* in the course of reproduction if success were to be attained. Under the conditions of this experiment, proficiency of performance seemed to be contingent upon the formation of a kind of "thingness" of the last portion of a just-exposed number.

SUMMARY AND CONCLUSIONS

This experiment was an attempt to discover what relationships may exist between the temporal order of presentation of material and the learning process. In the light of recent attempts to express a learning theory in terms of conditioned reflexes, this issue is of importance. The results of this study were not in harmony with this concept of learning as conditioning.

It was shown that the demanded identity between the conditions of simultaneous and successive exposure of material to be learned did not hold for the memorization of twelve place digits. Such similarities between the two types of presentation as were found could be shown to be due to such factors as practice, atti-

tude, etc., rather than to any conditions operative because of stimulation sequence itself. It was demonstrated that for subjects trained under the condition of a single durational exposure, the condition of successive exposure offered a new problem which demanded an altogether different type of attack and method. The two types of exposure were shown (after specifically training the observers) to result in about the same efficiency of reproduction although the manner in which this goal was attained differed widely. Frequency and duration have in common only the fact that under either condition of exposure a trained subject will learn.

Under the conditions of this experiment the following conclusions may be drawn:

1. Under the present conditions of experimentation frequency and duration are not synonymous or interchangeable.
   a. The practice effect apparent under the condition of successive exposure did not apply to re-tests under the condition of a single exposure.
   b. Verbal reports from the subjects indicated a rather fundamental difference between the problem under the two varied conditions of presentation.
2. Whenever an attempt is made experimentally to isolate any of the various factors operative in the learning process, it is important that all subjects should be and remain on the same general level of performance.
3. There was found but scant evidence that learning under these conditions partakes of the nature of the formation of delayed conditioned reflexes.
4. There was practically no evidence for the functioning of any form of "interference" between numbers exposed in sequence.
5. Reproduction alone may be a poor measure of what actually is taking place during learning under the conditions of this experiment.

   It was shown that a criterion of performance such as the excellency of reproduction gave no indication of the functioning of such factors as: the difficulty of the prob-

lem itself, the manner of grouping and remembering, changes in attitude, the *amount* of work necessary for success, etc.

6. The process of perceiving and memorizing was again (39), (21) shown to be a smooth, ballistic performance, any deviation from which becomes lethal to success.
7. Visual imagery of a sort was shown to play a rather important role in the total process.

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NEW GENERA OF PENNSYLVANIAN CRINOIDS FROM KANSAS, OKLAHOMA AND TEXAS

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INTRODUCTION

It is the purpose of this paper to describe two interesting types of crinoids that have been found to occur in the Pennsylvanian rocks of Kansas, northern Oklahoma and Texas. These crinoids are strikingly different in form, one being marked by the highly thickened nature of the radial plates and very low, discoidal appearance of the dorsal cup, and the other having an unusually narrow, steep-sided cup. Both kinds are distinguished at a glance from previously described genera. The first discovered specimens were obtained in 1938, and in the case of the steep-sided form, only infrabasal circlets attached to a portion of stem were found until after considerable collecting. Complete cups

are rare, but it is now possible to identify them on the basis of fragmentary material, and because remains are known from various horizons in Kansas, Oklahoma and Texas, it is reasonable to conclude that they will prove to have stratigraphic value. The low, discoidal crinoid is named *Galateacrinus*, from the graceful, beloved friend of Pygmalion, and the tall, slender cup is termed *Elibatocrinus*, from the Greek, *elibatos*, meaning steep or abrupt.

Designation of structural elements of the crinoids, as given in the following descriptions, follows the convenient abbreviations established by Bather and by Wachsmuth and Springer. These are now standard in paleontologic literature on crinoids, but are explained in previous papers (Moore and Plummer, 1938, 1940; Moore, 1939, 1939a), which also give discussions of orientation of individual crinoid plates and preparation of cross sections of crinoid cups.

Geologic Distribution.—The lowest stratigraphic horizon represented by crinoids here described is in the upper part of the Oologah limestone of northeastern Oklahoma. This is equivalent to the Altamont limestone of Kansas, the main lower part of the Oologah corresponding to the Pawnee limestone farther north. The upper Oologah crinoid-bearing beds belong in the upper part of the Des Moines series (see Moore, 1936, 51), approximately 1000 feet above the disconformity at its base and about 300 feet below the disconformity at its top. A much greater thickness of Pennsylvanian rocks underlies the horizon of the Oologah in south-central and southern Oklahoma than in the northeastern part of that state, where Mississippian rocks occur at a distance of 1200 feet or less below the Oologah limestone. Several well preserved specimens of *Galateacrinus stevensi*, n. gen., n. sp., and numerous dissociated plates belonging to this species have been collected from beds of Altamont age (upper Oologah) at the Garnett quarry, about seven miles northeast of Tulsa, Okla., by Bob Stevens.

The next higher occurrence of *Galateacrinus* is at a horizon in the Coffeyville shale about 30 feet above the lower boundary of the Missouri series. A single dorsal cup, designated as *G. ornatus*,

n. gen., n. sp., and several radial plates have been collected in an old brick pit at Coffeyville, Kansas, from a shaly limestone that is regarded as probably equivalent to the Checkerboard limestone of Oklahoma.

Another specimen of *Galateacrinus* that differs in shape and ornamentation from other observed examples, apparently representing a distinct species, has been collected by Paul McGuire from the upper Cherryvale shale near Ramona, Okla. This horizon belongs about 600 to 700 feet above the base of the Missouri series in the latitude of Ramona.

The Iola limestone, in the upper middle part of the Missouri series of eastern Kansas, some 400 feet above the base of the series, but about 100 feet stratigraphically higher than the Cherryvale horizon, has furnished good specimens of *Galateacrinus* and *Elibatocrinus* in the cement quarry at Iola, Kans. These include the types of *G. allisoni*, n. gen., n. sp., and a paratype of *E. leptocalyx*, n. gen., n. sp.

From the Wyandotte limestone, a little over 100 feet above the Iola, a complete dorsal cup of *E. leptocalyx* was collected in a quarry at Loring, on Kansas River.

The next higher horizon that is represented by these crinoids is the Plattsburg limestone, which in central-eastern Kansas is about 100 feet above the Iola limestone. The Plattsburg has furnished specimens that are referred to *E. leptocalyx* and also the type of *E. notabilis*, n. gen., n. sp. These were collected at a locality 2.5 miles west of Neodesha, Kans.

The Stanton limestone overlies the Plattsburg, intervening beds ranging from about 5 to 100 feet. The holotype and paratypes of *E. leptocalyx* have been obtained from the Stanton, the localities being distributed from southern to northeastern Kansas.

Both *Galateacrinus* and *Elibatocrinus* range into lower Virgil beds. The former genus is represented by a dorsal cup, apparently unlike species from lower beds but somewhat too poorly preserved to be described. This occurs in the Oread limestone near Lawrence, Kans. The types of *E. concinnulus*, n. gen., n. sp., and *E. catactus*, n. gen., n. sp., come respectively from the Vinland shale, about 100 feet above the base of the Virgil series, and from the Oread limestone, approximately 200 feet above the

Vinland horizon. No specimens of either genus have been found above the Oread limestone.

No specimens of *Elibatocrinus* have yet been identified in collections from Oklahoma and Texas, although it is probable that they will be discovered. Radial plates of *Galateacrinus* occur sparingly in upper Des Moines and lower Missouri beds of Texas. The type of *G. ewersi*, n. gen., n. sp., was collected from the Graford formation, in the lower part of the Missouri series, near Joplin, Texas.

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SYSTEMATIC DESCRIPTIONS

Order INADUNATA Wachsmuth and Springer

Family POTERIOCRINITIDAE Roemer[1]

Genus ELIBATOCRINUS, n. gen.

Dorsal cup steeply conical in form, with three IBB in the lowermost circlet, clearly visible from the side. The proximal parts

[1] Earlier papers (Moore and Plummer, 1938, 236; Moore, 1939a, 198) that list this family in the name of Bassler are believed to have been incorrect in transferring designation of authorship from Roemer to Bassler, since it was Roemer who formulated the concept of this family on the basis of a type genus, *Poteriocrinites* Miller, which he improperly followed authors in calling *Poteriocrinus*. Bassler merely emended the spelling to make it conform to the correct designation of the type genus.

of the IBB are thickened internally and the circlet commonly remains joined to a portion of the stem. The five RR have short facets and straight transverse ridges that are slightly narrower than the greatest width of the RR. Three anal plates are present in the cup, the RA resting on the pB and rpB. The tegmen, arms and stem are unknown.

Discussion.—This genus is erected on the basis of three complete dorsal cups and about a dozen IBB circlets with attached portions of the column. Only four other poteriocrinid genera having three IBB and three anal plates in the cup have been described and each of these is very evidently distinct from the Pennsylvanian forms found in Kansas. *Mollocrinus* Wanner and *Trimerocrinus* Wanner, from the Permian of Timor, have subglobular cups, the former with very short rounded radial facets that face steeply outward, and the latter with facets sloping inward. *Tribrachiocrinus* Etheridge, from Permian of Australia, has only three arm-bearing rays on the subglobular dorsal cup. *Alsopocrinus* Tansey, from Middle Devonian rocks of eastern Missouri, is based on a single low conical cup that differs from *Elibatocrinus* in the very low IBB circlet, which is barely perceptible from the side. In each of the first three genera mentioned, the small IB occurs in the anterior ray, and in *Alsopocrinus* the position of this plate is not definitely indicated.

Genotype.—*Elibatocrinus leptocalyx*, n. sp.

Occurrence.—Missouri and Virgil series, Pennsylvanian (Upper Carboniferous), Kansas.

Elibatocrinus leptocalyx, n. sp.

Plate 1, figures 2a–c, 3, 4, 5a, b, 6; text figures 1a–d, 2a, b, 3

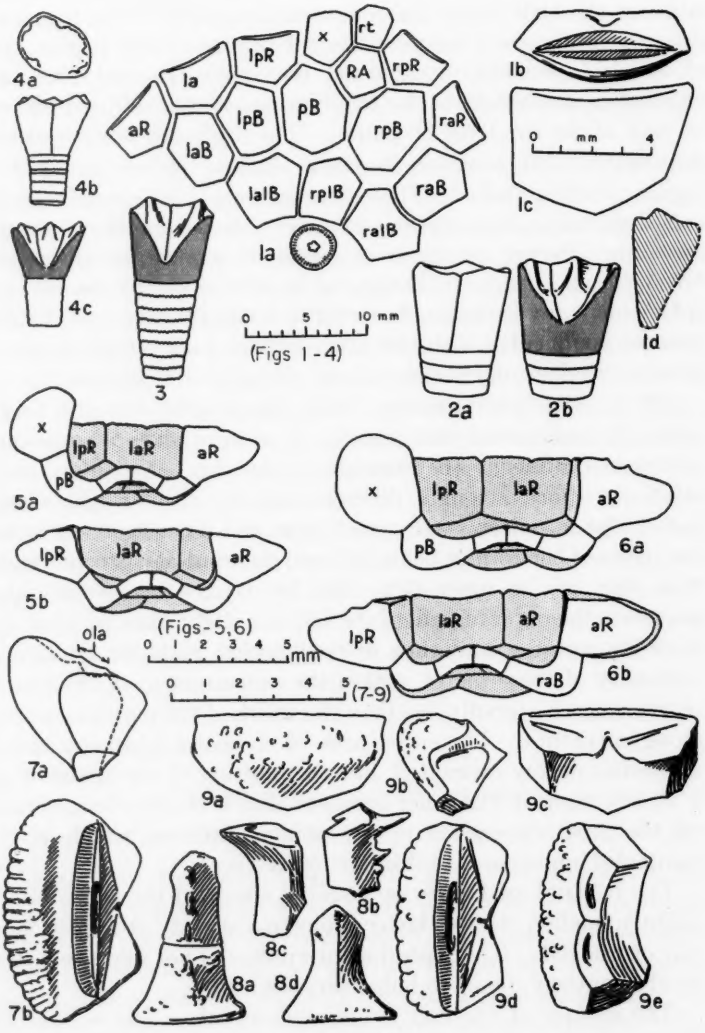
Dorsal cup a slender steep-sided cone, with greatest width slightly less than the greatest height, which is at the posterior side of the cup. IBB 3, consisting of one small and two large plates, the small one being uniformly located in right posterior ray; proximal one-third bearing portion of the round stem impression, distal two-thirds sloping very steeply upward. The lower part of the IBB circlet is greatly thickened inside so as to form a conical or paraboloid hollow with base some distance

above the proximal columnal (see text figs. 2b, 3). The distal edges of the IBB plates are thin, delicately marked by ligament grooves, and show a buttress-like thickening at five points, one of which is centrally located on the small IB, and two, corresponding in position to the tips of antecedently unfused plates, on each of the two large IB plates. The thickened areas broaden downwards and coalesce, forming shallow niches above the region of their union. These features are very prominent in some specimens, less distinct in others, but since they are observed in different species, they appear to be a generic character. BB 5, longer than wide, hexagonal in outline except the pB and rpB which are heptagonal; straight longitudinally and flaring upward confluently with the IBB, curved transversely so as to produce shallow depressions along the inter-BB sutures.

RR 5, with width nearly twice the length, straight longitudinally and curved transversely so as to produce a somewhat scalloped outline at the summit of the cup. Articular facets relatively short, strongly differentiated by the straight transverse ridge into deeply excavated outer and inner ligament areas, the plane of the former being inclined outward at a steeper angle than that of the inner (text figs. 1b–d); the transverse ridge intersects the outer margin of the RR at a slight distance from the inter-RR sutures, and this, in conjunction with the transverse convexity of these plates, makes the measurement of the length of the ridges materially less than the width of the plates measured along curvature. The entire area of the outer ligament area is somewhat deeply excavated, but the position of the ligament pit is clearly marked; the inner ligament area is chiefly characterized by the great depression of the oblique furrows, which give a channeled appearance to this part of the facet.

The RA and anal x are subequal in size, and the rt plate only slightly smaller, the two latter projecting slightly above the summit of the RR. The posterior interradius is not depressed, but, on the contrary, tends to bulge very slightly.

The surface of the cup is entirely smooth. The sutures are distinct but not impressed. The round stem segments bear 38 to 42 very short crenellae; the edges of the columnals are longi-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9a
9b
9c
9d
9e
8a
8b
8c
8d

FIGS. 1–9

tudinally straight and smooth; each segment is pierced by a moderately large pentalobate lumen. Arms and tegmen unknown.

Included among the paratypes are several specimens of IBB circlets with attached portion of the stem, some with more than a dozen columnals. There are slight variations in the proportions

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FIGS. 1–3—*Elibatocrinus leptocalyx*, n. gen., n. sp., *1*, The holotype specimen from the Stanton limestone at Fredonia, Kans. *a*, Analysis of plates of the dorsal cup; an accurate camera lucida drawing; *b*, Dorsal view of the anterior radial of the holotype, showing very prominent transverse ridge and deeply excavated parts of the outer and inner ligament areas. *c*, Front view of the anterior radial. *d*, Median profile of the anterior radial. *2*, An infrabasal circlet and three attached columnals, from the Stanton limestone at Ottawa, Kans. *a*, Exterior view, the laIB at right. *b*, Vertical section, showing the greatly thickened lower part of the circlet, the buttresses and niches on the sides of the central cavity, and the small rpIB in the middle part of the figure. *3*, Another infrabasal circlet from the Stanton limestone at Ottawa, Kans., sectioned vertically; the raIB at right.

FIGS. 4a–c—*Elibatocrinus notabilis*, n. gen., n. sp., the holotype specimen, from the Plattsburg limestone near Neodesha, Kans. *a*, Ventral view, showing thickened parts of plates at buttresses, the small rpIB above and slightly to right. *b*, Exterior view, the laIB at right. *c*, Vertical section, showing conical central cavity, the small rpIB at middle.

FIGS. 5a, b—*Galateacrinus allisoni*, n. gen., n. sp., Median cross sections of the holotype specimen, from the Iola limestone at Iola, Kans. *a*, Section through the posterior basal and anterior radial, showing the left half of the cup, shaded area beyond the plane of the section. *b*, Section through the center of the left posterior radial and right anterior basal.

FIGS. 6–8—*Galateacrinus stevensi*, n. gen., n. sp. *6*, Cross sections of the holotype specimen, from the Oologah limestone near Tulsa, Okla. *a*, Section through the posterior basal and anterior radial, showing the left half of the cup, shaded area beyond the plane of the section. *b*, Section through the center of the left posterior radial and right anterior basal. *7*, A separated radial plate, from the same horizon and locality as the holotype. *a*, Side view showing median longitudinal profile, the dotted line being a part of the profile concealed from the side (ola—outer ligament area). *b*, Top view of plate, showing facet and laterally projected flangelike extension. *8*, Primibrachs of a paratype, from the same horizon and locality as the holotype. *a*, Front view of quadrangular first and auxiliary second primibrach of the left anterior ray. *b*, Side view of upper plate shown in 8a. *c*, Side view of auxiliary first primibrach. *d*, Front view of same showing narrowed distal part.

FIGS. 9a–e—*Galateacrinus ornatus*, n. gen., n. sp. Drawings of a dissociated radial plate from the Coffeyville shale at Coffeyville, Kansas. *a*, Front view. *b*, Side view showing medium longitudinal profile. *c*, View from interior side. *d*, Top view showing facet. *e*, View from below.

of the IBB circlet, the ratio of height to width ranging from 0.65 to 0.95, and the angle of the steeply inclined sides ranging from about 8 to 16 degrees from the vertical. All of the IBB plates are smooth, and are characterized by the marked thinness of the distal margins, excepting small areas near five points distributed between the inter-IBB sutures as described. Proximal thickening of the entire area of the plates produces a rounded conical depression on the interior of the cone, the base being perforated by a pentalobate opening leading to the columnals. The edges of the columnals are straight longitudinally and confluent across suture lines in such degree that only on somewhat weathered specimens are the serrate edges of the crenellae clearly visible. A very fine, almost imperceptible longitudinal striation appears on parts of the stem, and is probably a characteristic feature of fine ornamentation. The narrow suture faces at the distal extremities of the IBB, measuring somewhat less than 0.5 mm. across, are marked by numerous fine ridges and grooves for articulation with the plates of the succeeding circlet.

Measurements of the holotype and three paratypes, in millimeters, are shown in the following tabulation:

Measurements of *Elibatocrinus leptocalyx*, n. gen., n. sp.

	HOLOTYPE	PARATYPES		
	4548	5910	5973	3112
Height of dorsal cup	12.0	10.4		
Greatest width of cup	11.5±	10.±		
Ratio height to width				
Length of radial (aR)	3.8	3.1		
Width of radial (aR)	6.3	6.0		
Length of transverse ridge	4.7	3.9		
Length of basal (raB)	6.5	6.0		
Height of IBB circlet	4.2	4.0	6.8	6.3
Width of IBB circlet	6.8	5.5	7.6	8.0
Width of stem impression	3.8	2.8	5.7	4.0

Discussion.—This crinoid is readily distinguished from all other known Upper Carboniferous crinoids of conical form by the three IBB. *E. leptocalyx* differs from other observed species by its relatively large size, straight, smooth sides, and straight-sided stem, lacking in annulations.

Occurrence.—Iola limestone, Kansas City group, Missouri series, Univ. Kansas loc. 3112, cement plant at south edge of Iola, Kans. (paratype, IBB circlet and attached stem, collected by R. C. Moore); Island Creek shale member of the Wyandotte limestone, Kansas City group, Missouri series, Univ. Kansas loc. 5910, quarry at Loring, Kans., (paratype, dorsal cup collected by N. D. Newell); Hickory Creek shale member, Plattsburg limestone, Lansing group, Missouri series, Univ. Kansas. loc. 4610, on State Highway 96, 2.5 miles west of Neodesha, Kans. (paratypes, two IBB circlets and attached columnals, collected by R. C. Moore); Stoner limestone member, Stanton limestone, Lansing group, Missouri series, Univ. Kansas loc. 4548, Fredonia cement quarry, Fredonia, Kansas, (holotype, dorsal cup, collected by W. L. Stryker and R. C. Moore); Stanton limestone, Univ. Kansas loc. 4602, Wood Bros. quarry, southwest of LeLoup, Franklin County, Kans. (paratypes, 3 IBB circlets, collected by Arthur Bridwell); Stanton limestone, Univ. Kansas loc. 5973, Ross quarry, southeast of Ottawa, Kans. (paratypes, 3 IBB circlets with attached stems, collected by Arthur Bridwell and Allen Graffham); Stanton limestone, Univ. Kansas loc. 6018, railroad cut one mile southwest of Wayside, Kans. (paratypes, 5 IBB circlets, collected by R. C. Moore); all Pennsylvanian (Upper Carboniferous).

Types.—Holotype and paratypes deposited in the U. S. National Museum.

Elibatocrinus notabilis, n. sp.

Plate 1, figures 7a–b; text figures 4a–c

This species is discriminated on the basis of a single well preserved IBB cone and attached portion of the column. Although, in a majority of cases, the type specimens of crinoid species are incomplete, it is rarely possible or desirable to attempt description of a species on the basis of a mere fragment of the dorsal cup. In the present instance, there can be no doubt as to the generic affinities of the specimen in hand, and its distinctive features of ornamentation make it readily recognizable.

The sides of the IBB circlet slope steeply upward, making an

angle of about 13 degrees with the vertical. The distal rim is marked by five moderately sharp-pointed projections and as many intervening notches; each of the points is distinctly thickened and there are rib-like extensions beneath the points, but no arcuate shelves between them. Except for an area about 0.5 mm. in width along the distal extremities of the plates, the surface is marked by a pattern of rather coarse rounded tubercles, unevenly distributed in the proximal region but arranged longitudinally in the distal area. The height of the IBB circlet is 5.1 mm.; its width at the summit, 5.7 mm.; diameter of proximal columnal, 3.8 mm.; diameter of ninth columnal below cup, 3.0 mm. The sides of the round stem are smooth, the surfaces of adjoining segments being confluent. The length (thickness) of the columnals ranges from about 0.1 to 0.8 mm.; the distal face of the ninth columnal bears 35 short even crenellae, about 0.5 mm. in length.

Remarks.—The ornamentation of *E. notabilis* serves to distinguish it readily from other observed species of the genus.

Occurrence.—Hickory Creek shale member, Plattsburg limestone, Lansing group, Missouri series, Univ. Kansas loc. 4610, on State Highway 96, 2.5 miles west of Neodesha, Kans.; collected by R. C. Moore.

Type.—Holotype deposited in the U. S. National Museum.

Elibatocrinus concinnulus, n. sp.

Plate 1, figure 8

A comparatively small and delicate species of *Elibatocrinus* that occurs in lower Virgil beds is represented in the collections by a well preserved specimen showing the proximal portion of the column and the IBB circlet. The circlet differs from others in the slightly bowl-shaped appearance, which is due to longitudinal curvature of the plates, and a relatively low height as compared to the width. The division of the circlet in three unequal plates is very clearly shown, and on the inside there is a pronounced thickening that is accompanied with development of buttresses beneath points of the IBB. The surface is marked by a barely

perceptible roughness that produces a shagreened appearance; this is not due to weathering but is a type of surface decoration.

The stem is rather strongly annulated, with alternating large and small segments that have curved longitudinal profiles and that are marked by vertical grooves and ridges. The diameter of the proximal columnal (2.2 mm.) is slightly greater than any of the others and distinctly greater than the one at the distal extremity (1.7 mm.) of the remnant portion of the stem.

The height of the IBB circlet is 2.4 mm.; its diameter at the top, 3.5 mm.; depth of concavity inside the circlet, 0.8 mm.

Remarks.—The small size and delicate pattern of surface markings of *E. concinnulus* suggest comparison with *E. catactus*, from the Oread limestone, about 200 feet above the Vinland shale. The sides of the IBB circlet in the latter species are not at all curved longitudinally, the surface decoration is more definitely arranged with vertically trending fine, low elevations, and the interior of the circlet shows a different appearance of the buttresses. The stem of *E. catactus* is not known, but the nature of the stem of *E. concinnulus* is evidently unlike that of *E. leptocalyx* and *E. notabilis*.

Occurrence.—Vinland shale member, Stranger formation, Douglas group, Virgil series, Univ. Kansas loc. 4564, O'Brien farm, four miles northeast of Baldwin, Kans.; holotype collected by Arthur Bridwell.

Type.—Holotype deposited in the U. S. National Museum.

Elibatocrinus catactus, n. sp.

Plate 1, figures 1a–c

Dorsal cup small, with steeply conical form and very straight sides, height greater than maximum width. The IBB circlet is one-third as high as the entire cup; the small IB is located in the right posterior ray. Paratypes, consisting of IBB circlets that are apparently identical to this part of the holotype specimen, show the well marked differentiation of buttresses beneath the five points and a broadly curved, very distinct shelf-like connection between the buttresses; the niches just above these shelves are unusually prominent and the appearance of the inside of the

circlet suggests a five-lobed trumpet. The BB are longer than wide, straight longitudinally but curved transversely so as to produce furrows along each of the inter-BB sutures. The RR, also, are longitudinally straight but transversely curved strongly enough to give the outline of the cup in ventral view a definitely scalloped appearance. The straight transverse ridges of the facets are prominently elevated and intersect the margins of the RR at a short distance from the inter-RR sutures; the general plane of the outer ligament areas slopes moderately outward, whereas that of the inner ligament area is approximately horizontal; the length of the entire facet is a little less than one-half of the width.

The three anal plates of the cup are in normal arrangement and their relative sizes are almost exactly the same as in *E. leptocalyx*. The nature of the arms and stem is unknown. The surface of the cup is faintly but definitely ornamented by low, slightly uneven elevations and depressions that trend vertically in general, but in places appear oriented normal to the margins of the plates.

Measurements of the holotype specimen are as follows: height of dorsal cup, 8.4 mm.; greatest width of cup, 6.8 mm.; height of IBB circlet, 2.5 mm.; width of IBB circlet at top, 3.5 mm.; diameter of stem impression, 2.1 mm.; the stem impression is marked with 26 short crenellae. A paratype, consisting of an IBB circlet has a height of 3.8 mm.; depth of central concavity, 2.8 mm.; width at summit, 4.6 mm.; diameter of stem impression, 2.4 mm.; diameter of pentalobate lumen, 0.5 mm.

Remarks.—The form and proportions of the dorsal cup of *E. catactus* are not distinguishable from those of *E. leptocalyx*, but the Oread species is smaller and is delicately ornamented, instead of smooth. Comparison of *E. catactus* and *E. concinnulus* has been given under discussion of the latter species.

Occurrence.—Plattsmouth limestone member, Oread limestone, Shawnee group, Virgil series, Univ. Kansas. loc. 6045, along roadway 3.5 miles east of Lecompton, Kans. (holotype, dorsal cup, collected by Scott Ellis). Toronto limestone member, Oread limestone, Univ. Kansas loc. 4570, quarry in sec. 27, T. 13 S.,

R. 19 E., southwest of Lawrence, Kans. (paratypes, four IBB circlets, collected by Arthur Bridwell). An IBB circlet much larger than the four paratypes, obtained from the same horizon and locality, clearly belongs to *Elibatocrinus* but is not identified as *E. catactus*, for it appears to be smooth, the interior markings are different, and it is approximately twice as large as the other specimens (height 6 mm., width at summit, 7 mm.)

Types.—Holotype and paratypes deposited in the U. S. National Museum.

Genus GALATEACRINUS, n. gen.

Dorsal cup discoid, the circlet of RR projecting laterally very prominently and rather sharply separated from the BB; base gently concave. IBB five, relatively small, flaring gently downward, not visible in side view of the cup. BB five, sub-equal, somewhat bulbous, clearly visible in side view of the cup, tangent to basal plane of cup at about their mid-length. RR five, extremely convex in longtiduinal profile, their proximal and distal areas nearly horizontal, with intervening area produced laterally as a flange; articular facets sub-horizontal, short, distinctly narrower than greatest width of RR, but with ends of neighboring transverse ridges almost touching. Three anal plates in the cup. First primibrachs axillary in at least three of the rays. Stem round.

Discussion.—The observed characters of the dorsal cup in *Galateacrinus* are not very closely similar to those of any known genus. *Benthocrinus* Wanner has very prominent sub-horizontally directed RR that, like this new genus, are the chief elements of the dorsal cup, but the articular facets are not set inward and they slope rather strongly outward; the base of the cup in *Benthocrinus* is strongly concave, the BB are much reduced in size and there is only one anal plate. Among genera having three anal plates in the dorsal cup, *Galateacrinus* may be compared with *Linocrinus* Kirk in the general form of the cup, although the RR of *Linocrinus* do not bulge laterally very strongly. *Linocrinus* has axillary primibrachs in all but one of the rays and the arms

are keeled, as appears to be the case in *Galateacrinus*. There is little other similarity and it does not appear that these two genera are closely related.

Genotype.—*Galateacrinus stevensi*, n. sp.

Occurrence.—Des Moines to Virgil series, Pennsylvanian (Upper Carboniferous), Kansas, Oklahoma and Texas.

Galateacrinus stevensi, n. sp.

Plate 1, figures 9a–d, 10; text figures 6a, b; 7a, b; 8a–d

Description of this small but very distinctive species of crinoid is based on five dorsal cups, one of which carries a number of the primibrach plates.

The dorsal cup is nearly circular in outline and in dorsal view appears distinctly flower-like, the projecting RR resembling the petals and the small BB suggesting the clustered center of a flower. The RR and BB circlets are separated in such fashion that when the cup is inverted, the BB circlet is like the low crown of a broad-brimmed hat. The IBB circlet, however, is so confluent with the BB that it is difficult to see the divisions between plates of these circlets. The height of the cup is a little less than one-third of the greatest width. The five IBB form a slightly stellate pentagon, with only the distal extremities appearing beyond the margin of the stem impression; this part of the plates flares distinctly downward (Figs. 6a, b); the proximal two-thirds of each IB is covered by the round stem impression. On the interior of the cup the IBB circlet forms a low rounded cone. The BB flare downward in the proximal region and curve abruptly upward to a subvertical position in the distal region. These plates are moderately convex transversely and there are shallow depressions along each of the inter-BB sutures. The pB and rpB are very slightly larger than the other plates of this circlet and are heptagonal in outline instead of hexagonal. The longitudinal mid-profile of the RR is sub-horizontal in the proximal part, curved gently upward at mid-length, and then bending very sharply, it is sub-horizontal or slopes gently upward and inward in the distal one-third of its length (Figs. 6a, b). Transverse curvature produces furrows between each of these plates. The articular facets are relatively

short and the plane of both outer and inner ligament areas is nearly horizontal. The outer ligament area is gently hollowed and is marked by fine denticles arranged transverse to the outer marginal ridge; ligament pit is well defined but not very large (Figs. 7a, b). The transverse ridge is prominent but is not marked by denticles. The inner ligament area contains ill-defined oblique furrows that are confluent with the simple concave muscle areas; there is a distinct short intermuscular furrow but only a slight intermuscular notch; lateral ridges are strongly marked but not elevated and between those of adjacent facets there are hollows formed by the adsutural slopes. The arrangement of the anal plates is normal in all of the types except one, the RA touching the rpB and anal x resting against the distal extremity of pB. In one of the paratypes the RA comes within about 1 mm. of the rpB but does not touch it and the anal x is shifted upward so that it is not in contact with the pB; the rt of this cup is much reduced in size and is practically excluded from the cup.

The round stem impression is marked by about 18 crenellae that extend half-way inward to the small round lumen. The surface of the dorsal cup is ornamented by coarse granules and irregular narrow ridges that trend mostly parallel to the longitudinal axis of the plates. The granulose ornamentation appears chiefly on the IBB circlet and near the margins of the other plates; the ridges are most evident on the bulbous mid-portions of the BB and especially on the RR.

The primibrach plates, which are attached to one of the paratypes, are somewhat elongate axillaries in three of the rays (see Figs. 8c, d); these plates are distinctly narrowed in the middle and upper parts and they curve outward to a sharp point at the distal extremity. In one of the rays (left anterior) there is a quadrangular first primibrach (Fig. 8a) with length about equal to width and this is followed by a long very narrow axillary plate which bears a spinose median keel (Figs. 8a, b). Somewhat fainter keels are observed on the other primibrachs.

Measurements of the holotype and a paratype in millimeters are as follows:

Measurements of *Galateacrinus stevensi*

	HOLOTYPE	PARATYPE
Height of dorsal cup	3.4	3.2
Greatest width of cup	13.1	10.5
Ratio of H to W	.26	.30
Diameter of stem impression	1.8	1.4
Greatest width IBB circlet	2.7	2.4
Greatest width BB circlet	7.3	6.2
Diameter of body cavity	6.8	5.9

Discussion.—The specimens of *G. stevensi* that have been described are not at all similar to any other known crinoid from the Des Moines series but they resemble species belonging to this genus from the Missouri beds in Kansas and Texas. *G. ornatus,* from the Coffeyville is a slightly smaller species with less protuberant RR that is characterized by the more tuberculated nature of its decoration. *G. allisoni* is a smooth form.

Occurrence.—Oologah limestone, Univ. Kansas loc. 4589, Garnett quarry, seven miles northeast of Tulsa, Oklahoma. Collected by Bob Stevens.

Types.—Holotype, and paratypes, deposited in the U. S. National Museum.

Galateacrinus ewersi, n. sp.

Plate 1, figures 12a–d

Dorsal cup very low, discoid, with turreted form produced by bulging BB circlet and flat expansion of the RR at a level slightly above the basal plane of the cup. The IBB form a pentagon in a sharply defined basal concavity, mostly covered by the round stem; the distal tips of these plates flare distinctly downward. The BB are strongly bulbous, the proximal margins of each forming a straight vertical wall that is 0.5 mm. or slightly more in height; median portions of the BB moderately rounded transversely and longitudinally, with distal margins subvertical. The RR extend almost horizontally outward, so that an angle of about 90 degrees is formed at their juncture with the BB; the distal part curves abruptly upward and inward so as to form a flange-like projection that forms one of the most striking features of the

cup. The strongly elevated outer marginal ridge bounds the outer ligament area; ligament pit large and prominent. The inner ligament area is relatively short and slopes outward; it is divided by a broad intermuscular notch. Three strongly bulbous anal plates are present in the dorsal cup; they have a normal arrangement with the RA barely touching the rpB, and anal x resting on the truncated tip of the pB. Deep angular hollows occur along the juncture of these plates.

A few of the arm plates are in position above the RR. The first primibrachs are axillary plates that have an hour-glass outline, narrowing distinctly toward the top, with distal extremity projected in a point, but not produced in a spine. Both these plates and the IIBr bear faint longitudinal keels. The surface of the dorsal cup and arms is entirely smooth, but shallow depressions in the position of the inter-RR sutures and near the proximal tip of the RR give a slightly excavated appearance.

Measurements of the holotype specimen are as follows: height of dorsal cup 2.7 mm.; greatest width of dorsal cup 10.4 mm.; ratio of height to width, 0.26 mm.; width of IBB circlet 3.1 mm.; width of stem impression 2.5 mm.

Remarks.—The chief distinguishing features of this species are the lack of surface ornamentation, the straight, vertical-walled nature of the basal concavity, bulbous nature of the plates, and the outward slope of the facets and the flange just below the facets of the RR. These characters serve readily to distinguish this species from *G. stevensi* and *G. ornatus*. The outline of the cup differentiates *G. ewersi* from *G. allisoni*.

Occurrence.—Graford formation, Univ. Kansas loc. 6067, one-half mile west of Joplin, Jack County, Texas, Collected by J. D. Ewers.

Types.—Holotype deposited in the U. S. National Museum.

Galateacrinus allisoni, n. sp.

Plate 1, figures 11a–c; text figures 5a, b.

Dorsal cup very low, turreted, discoid, with rounded, moderately deep basal concavity; outline in dorsal or ventral view rounded subpentagonal. The IBB circlet forms a pentagon,

somewhat less than half of the length of each plate being occupied by the stem impression; the distal parts of these plates flare evenly down and outward. The BB are subequal, moderately tumid, the proximal parts confluent with the slope of the IBB, and the distal parts sloping steeply outward and upward. The RR extend subhorizontally outward so as to form a distinct but not strong angle with the BB, surface sharply rounded near the margin of the facets, but not produced in the form of a wide flange; in side view these plates appear gently arched transversely. The articular facets, which are very well preserved in the holotype specimen, are a little less than the maximum width of the RR; the outer ligament area is defined by a strong outer marginal ridge that bears evenly spaced strong but fine denticles; ligament pit moderately deep; adjoining areas shallow and smooth; transverse ridge sharp, without denticles; the inner ligament area is subhorizontal in the midportion but slopes distinctly outward in the lateral part, oblique furrows and intermuscular furrow well marked, lateral ridges and adsutural slopes distinctly developed. The three anal plates of the dorsal cup are gently rounded plates in normal position, the RA, which is subtriangular in outline, barely touching the rpB, the anal x plate resting against the truncated tip of the pB, and a narrow rt being inserted between the x and rpR.

The surface of the dorsal cup is entirely smooth. The round stem impression is relatively small and marked by about 13 even-sized crenellae. No arm plates are preserved.

Measurements of the holotype specimen are as follows: height of dorsal cup, 2.1 mm.; greatest width of cup 9.5 mm.; ratio of height to width, 0.22 mm.; width of IBB circlet, 2.5 mm.; width of stem impression, 1.4 mm.

Remarks.—In general form of the cup, this species most closely resembles *G. ornatus*, but it is distinguished by the lack of ornamentation of the plates. It is readily separated from *G. ewersi* by the different configuration of the plates, especially of the BB and the fuller, more evenly rounded surface of the RR.

Occurrence.—Upper part of the Iola limestone, Missouri series,

Univ. Kansas loc. 3112, Portland Cement quarry, Iola, Kansas. Collected by Robert Allison.

Type.—Holotype, deposited in the U. S. National Museum.

Galateacrinus ornatus, n. sp.

Plate 1, figures 13a, b; text figures 9a–e

Dorsal cup low, subcircular in outline, with circlet of BB differentiated in turret-like manner from the RR, as in other examples of the genus, relatively small. The IBB circlet regularly pentagonal in outline, a little more than one-half of each plate covered by the stem impression, the distal part flaring evenly downward; sutures at margin of the circlet clearly identifiable but not at all prominent. BB very tumid, the proximal parts with even downward and outward slope that is confluent with adjoining plates of the circlet and the IBB, distal parts curving to a vertical position at the extremities, and sides also sloping to an angled furrow along the inter-BB sutures. A narrow belt along the proximal edge of the RR is characterized by its nearly confluent attitude with the BB, and this belt is separated from the remainder of the plate by a sharply marked angulation; general form of the RR as in other species of the genus, but the laterally directed part is somewhat more evenly rounded and less extended than in some forms. The articular facets are divided by the transverse ridge into two planes that meet in an obtuse angle; the outer ligament area slopes outward, is moderately excavated, indistinctly delimited by an outer marginal ridge, and marked by distinct denticles and a wide short ligament pit; the inner ligament area shows strongly defined oblique furrows, a very narrow intermuscular furrow and a slight intermuscular notch. The stem is composed of alternating larger and smaller segments with longitudinally curved surfaces, giving the column an annulated appearance. The surface of the cup is decorated by rather closely spaced tubercles that are much larger on the RR than on the BB and IBB.

Measurements of the holotype specimen are as follows: Height of dorsal cup, 3.4 mm.; greatest width of cup, 10.7 mm.; ratio

of height to width, 0.32; width of stem, 1.8 mm.; width of IBB circlet, 3.0 mm.; width of BB circlet, 6.4 mm.

Remarks.—This species is most closely similar to *G. stevensi* from the Oologah limestone. It is differentiated by the granulose, instead of finely ridged, nature of its surface decoration, shorter and more evenly rounded RR, and more tumid, somewhat differently shaped BB.

Occurrence.—Shaly limestone (?Checkerboard) about 30 feet above the base of the Coffeyville shale, Missouri series, Pennsylvanian (Upper Carboniferous); loc. 4607, Univ. Kansas, old brick pit in the northwest part of Coffeyville, Kans. Collected by Lilian B. Moore.

Types.—Holotype (dorsal cup) and paratypes (radial plates), deposited in the U. S. National Museum.

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EXPLANATION OF PLATE 1

PAGE

Elibatocrinus catactus, n. gen., n. sp. 43

1—Holotype, a well preserved dorsal cup, from the Plattsmouth limestone member of the Oread limestone, Shawnee group, Virgil series, Pennsylvanian (Upper Carboniferous), 3.5 miles east of Lecompton, Kans. *a*, Posterior view, × 4; *b*, same, × 2; *c*, anterior view, × 4.

Elibatocrinus leptocalyx, n. gen., n. sp. 36

2—Holotype, a slightly crushed but complete dorsal cup, from the Stoner limestone member of the Stanton limestone, Lansing group, Missouri series, Pennsylvanian (Upper Carboniferous), at cement quarry, Fredonia, Kans. *a*, Posterior view, × 2; *b*, anterior view, × 2; *c*, ventral view, posterior side of cup below, × 2.

3—Paratype, a distorted cup, from the Island Creek shale member of the Wyandotte limestone, Kansas City group, Missouri series, Pennsylvanian (Upper Carboniferous), quarry at Loring, Leavenworth County, Kans. View from the anterior side, the aR at the upper left corner of the photograph, × 2.

4—Paratype, a complete IBB circlet with attached proximal portion of stem, showing irregular length of columnals and their straight, even sides, from the Hickory Creek shale member of the Plattsburg Limestone, Lansing group, Missouri series, Pennsylvanian (Upper Carboniferous), 2.5 miles west of Neodesha, Kans. View from the anterior side, the raIB at left, × 2.

5—Paratype, an IBB circlet with attached, slightly tapering, proximal portion of stem, showing barely perceptible sutures between columnals, from the Stanton limestone, Lansing group, Missouri series, Pennsylvanian (Upper Carboniferous), at Ross quarry, southeast edge of Ottawa, Kans. *a*, Side view, showing the raIB, × 2; *b*, ventral view, showing the funnel-like concavity with its five buttresses and intervening niches, the small rpIB at lower left, × 2.

6—Paratype, a slightly crushed IBB circlet, from the upper part of the Iola limestone, Kansas City group, Missouri series, Pennsylvanian (Upper Carboniferous), cement quarry at Iola, Kansas. Ventral view, showing the thin distal edges of the plates, the fine ligament grooves and ridges, and the moderately developed buttress-like thickenings below points of IBB, the small rpIB at the lower left, × 4.

Elibatocrinus notabilis, n. gen., n. sp. 41

7—Holotype, an almost perfect IBB cone with attached portion of stem, from the Hickory Creek shale member, Plattsburg limestone, Lansing group, Missouri series, Pennsylvanian (Upper Carboniferous), 2.5 miles west of Neodesha, Kans. *a*, View from the posterior side, the suture between the small rpIB (at right) and laIB in center of photograph, × 2; *b*, view from opposite side, all of the raIB and (at right margin) part of the laIB being shown, × 2.

Elibatocrinus concinnulus, n. gen., n. sp. 42

8—Holotype, a well preserved IBB circlet with attached portion of stem,

from the Vinland shale member, Stranger formation, Douglas group, Virgil series, Pennsylvanian (Upper Carboniferous), 4.5 miles northeast of Baldwin, Kans. Side view, the small rpIB at left, showing the annulated nature of the stem and crenulated appearance of the columnals, × 4.

Galateacrinus stevensi, n. gen., n. sp. 46

9—Holotype, a dorsal cup, from the upper part of the Oologah limestone, Marmaton group, Des Moines series, Pennsylvanian (Upper Carboniferous), from quarry at Garnett, about 7 miles northeast of Tulsa, Okla. *a*, Dorsal view, showing the flower-like appearance of the cup and the characteristic surface markings of the species, × 2; *b*, posterior view, indicating the very low discoid form of the cup, × 2; *c*, ventral view, showing the nearly plane, subhorizontal facets and the flangelike lateral projection of the radials, × 2; *d*, anterior view, × 2.

10—Paratype, a small specimen with primibrachs, from the same horizon and locality. Posterior view; the two primibrachs with spinous projections are attached to the raR, × 2.

Galateacrinus allisoni, n. gen., n. sp. 49

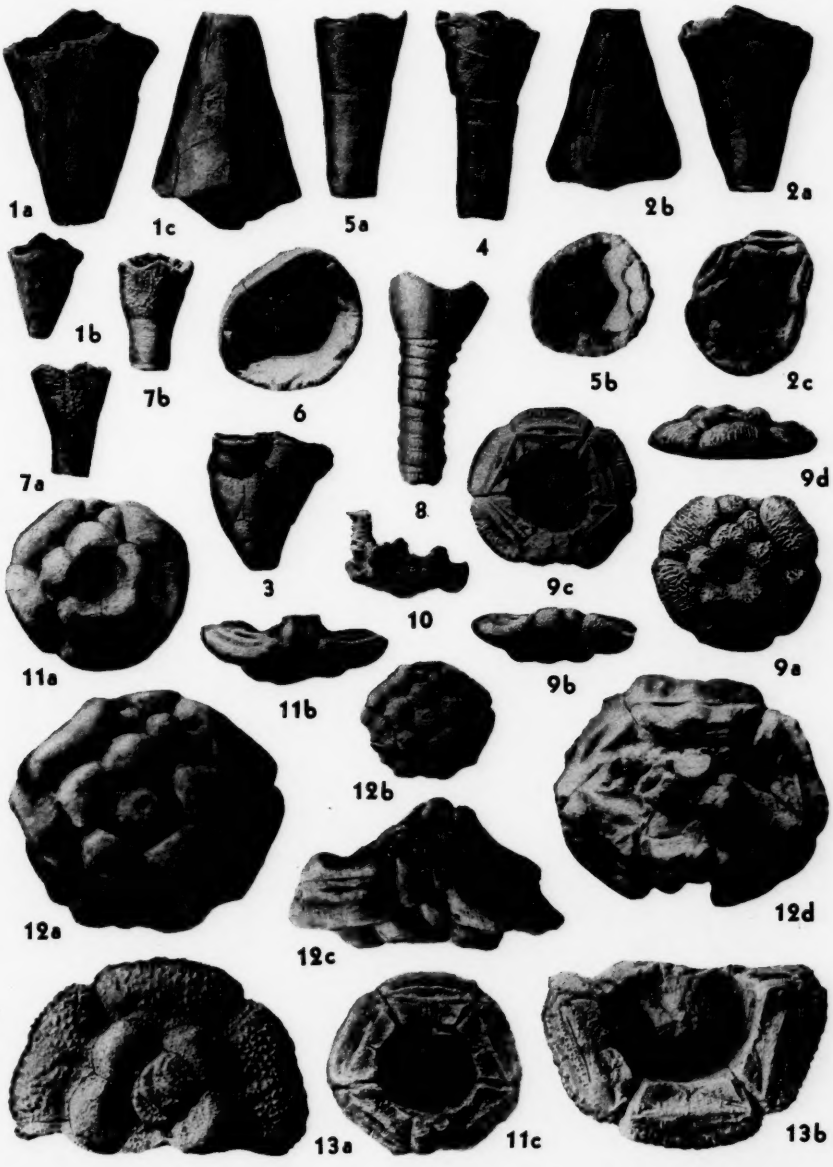
11—Holotype, a well preserved specimen, from the Iola limestone, Kansas City group, Missouri series, Pennsylvanian (Upper Carboniferous), cement quarry at Iola, Kans. *a*, Dorsal view, showing the smooth surface of the plates, × 2; *b*, posterior view, × 2; *c*, ventral view, × 2.

Galateacrinus eversi, n. gen., n. sp. 48

12—Holotype, a dorsal cup with a few attached primibrachs, from the lower part of the Graford formation, Canyon group, Missouri series, Pennsylvanian (Upper Carboniferous), about 0.5 mile west of Joplin, Jack County, Texas. *a*, Dorsal view, showing the deep narrow, straight-edged basal concavity and quadrate form of the radials, × 4; *b*, same, × 2; *c*, posterior view, showing the downward slope of the radials below the facets, ×4; *d*, ventral view, × 4.

Galateacrinus ornatus, n. gen., n. sp. 51

13—Holotype, an incomplete but excellent specimen showing most of the dorsal cup, from the lower part of the Coffeyville shale, Ochelata group, Missouri series, Pennsylvanian (Upper Carboniferous), at old brick pit in northwest part of Coffeyville, Kans. *a*, Dorsal view, showing the prominent circlet of tumid basals and the tuberculate ornamentation of the cup, × 4; *b*, ventral view, showing the relatively short lateral projection of the radial plates, × 4.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